MODELING HOT LAYER DEVELOPMENT IN STRUCTURAL FIRES[1]

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Structural fires result in significant capital loss and multiple deaths each year. These losses are decreasing with advances in fire protection engineering but further refinements require improved understanding and quantification of the conditions within a building during an interior structural fire, particularly the development of the hot ceiling gas layer. Modeling hot layer development in fires is very complex. Due to limited availability of real structures for full scale experimentation, as well as the costs involved, existing models of hot layer development generally have been tested using data from relatively well-controlled tests in enclosures with simple geometries. More comprehensive development and testing of such models requires data collected from controlled fires in real structures in order to describe real fire effects (leakage, ambient wind, failure of windows and doors, etc.), to determine the processes and boundary conditions important in realistic simulations of hot layer development and to identify limitations in existing models vis-à-vis prediction of hot layer growth during real structural fires.

This paper reports data obtained from five full scale fire tests in two residential structures, which were instrumented with twenty, 24 gauge, Type K thermocouples placed near the ceiling or at elevations of 1 m above the floor to monitor the development of temperature with time throughout the structures. The data, taken at approximately 2 s intervals throughout each test, is compared to predictions from three different models of hot layer development: 1) a correlation based model [1], 2) the ASET-BX model in FPETool [2] and 3) the CFAST model [3]. Limitations in the models are identified and recommendations made for potential improvements in their prediction of real fire scenarios.

Experimental data and model predictions for tests in two multi-room residential structures are plotted in Figures 1 through 4. Results from the correlation [1] and ASET-BX [2] models were for the room of fire origin only, while those from CFAST [3] were based on 5 and 8 room simulations of the structures. In Figure 1, the hot layer temperatures measured by T1 and T3 on the ceiling was overpredicted by all models, probably due to insufficient account for leakage of hot gases to the exterior of the structure. Inclusion of leakage factors in the correlations [1] and ASET-BX [2] only slightly improved the results, since no account could be taken of flow between internal compartments of the building. In contrast, lower layer temperatures (T2, T14) were well predicted by CFAST [3] until the hot layer descended below the thermocouple positions.

Figure 2 illustrates typical data compared to 5 and 8 room CFAST predictions [3] for hot layer development in a room on the upper floor of the structure. Hot layer temperatures were overpredicted, with significantly lower temperatures predicted in the 8 room simulation. This suggests excess enthalpy transport from the fire room through the structure, demonstrating a limitation in accounting for mass movement between compartments in a real fire scenario. Such overprediction may arise from the plume correlation used to model entrainment (which for real fires is often applied outside its range of validity) and/or from difficulties in modeling mass flow through ventilation openings from one section of the structure to another.

In Figure 3, although hot layer temperatures were initially overpredicted by all models, there was generally better agreement between the data and the predictions, probably due to the direct dependence of the fuel heat release rate correlation on measured values of hot layer temperature. Through this dependence, the shape of the measured hot layer temperature-time curve was mirrored in the heat release rate curve, and thereby reflected in predictions of hot layer temperature. In adjoining rooms, Figure 4, upper layer temperatures were slightly overpredicted, but trends were reasonable. In upper floor rooms,

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the predicted upper layer temperatures were in good agreement with the data, but lower layer temperatures were underpredicted. Again, refinements in the modeling of mass flux between compartments would be required to improve the predictions further.

Prediction of hot layer development in enclosure fires is very dependent on the accuracy of the submodels used for heat release rate of the fuel, for mass flow between compartments and for direct mass flow or leakage mass flow to the exterior of the structure. Limitations in these model elements are identified as major factors limiting application of current models of hot layer development to real fire scenarios; however, comparison of model predictions with real fire data suggests that these models can be improved to more accurately represent real fire conditions and thereby allow improved prediction of hot layer development during fires in multi-room structures.

1. McCaffrey, B.J., Quintiere, and M. Harkleroad, Fire Technology, 17, (2), 1981, p. 98.
2. Nelson, H. E., FPETool, Center for Fire Research, NIST, Gaithersburg, MD, 1991.
3. Jones, W. and G. Forney, NIST Technical Note 1283, Center for Fire Research, NIST, Gaithersburg, MD, 1990.

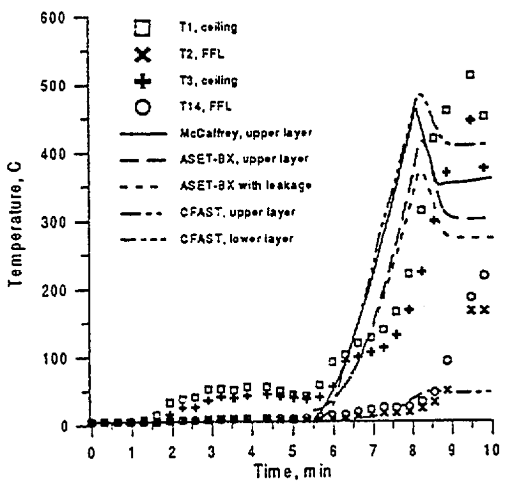

Figure 1: Upper and lower layer temperatures in fire room in multi-room fires in structure 1.

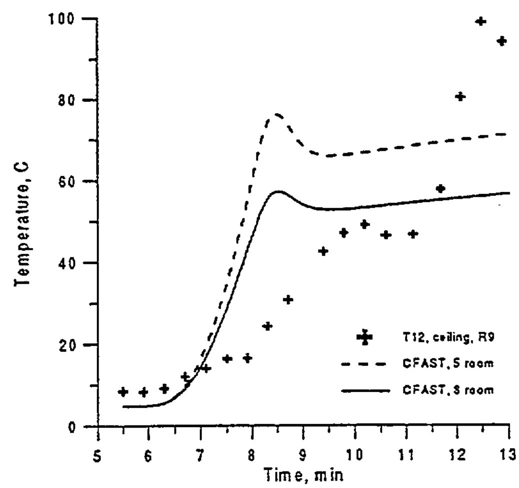

Figure 2: Upper layer temperatures in Room 9 on upper floor of structure 1.

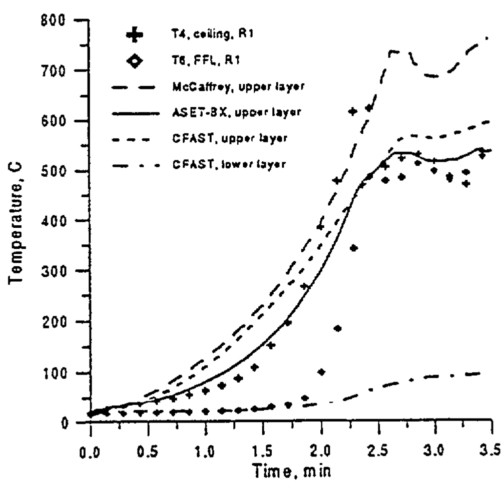

Figure 3: Upper and lower layer temperatures in fire room in multi-room fires in structure 2.

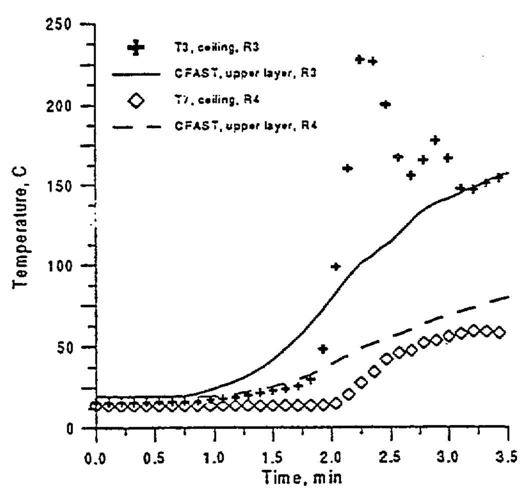

Figure 4: Upper layer temperatures in rooms adjoining fire room in structure 2.